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An integrated environmental and health performance quantification model for pre-occupancy phase of buildings in China

Li Xiaodong *, Su Shu, Zhang Zhihui, Kong Xiangqin

Department of Construction Management, School of Civil Engineering, Tsinghua University, Beijing, China

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ABSTRACT

To comprehensively pre-evaluate the damages to both the environment and human health due to construction activities in China, this paper presents an integrated building environmental and health performance (EHP) assessment model based on the Building Environmental Performance Analysis System (BEPAS) and the Building Health Impact Analysis System (BHIAS) models and offers a new inventory data estimation method. The new model follows the life cycle assessment (LCA) framework and the inventory analysis step involves bill of quantity (BOQ) data collection, consumption data formation, and environmental profile transformation. The consumption data are derived from engineering drawings and quotas to conduct the assessment before construction for pre-evaluation. The new model classifies building impacts into three safeguard areas: ecosystems, natural resources and human health. Thus, this model considers environmental impacts as well as damage to human wellbeing. The monetization approach, distance-to-target method and panel method are considered as optional weighting approaches. Finally, nine residential buildings of different structural types are taken as case studies to test the operability of the integrated model through application. The results indicate that the new model can effectively pre-evaluate building EHP and the structure type significantly affects the performance of residential buildings.

1. Introduction

Construction products contribute considerably to total energy consumption and also release considerable emissions to the environment, thus significantly damaging the natural environment and human health. Annual construction in China is expected to reach 2 billion square meters in the coming years as a result of high urbanization rates (55% in 2020) and rapid urban population growth (20 million annually) (Fang, 2009; Zhou, 2010). Buildings have become a major focus of attention in the recent age of sustainability in Chinese society. To scientifically identify major environmental impact factors and to effectively propose improvement measures, building environmental impact assessment (EIA) is necessary.

Life cycle assessment (LCA) methods are regarded as tools that help integrate environmental considerations with product development (Germani et al., 2004; Jeswiet and Hauschild, 2005; Wang, 2009). The LCA concept was first proposed by the Society for Environmental Toxicology and Chemistry (SETAC) in the 1990s. According to the International Organization for Standardization (ISO), the LCA framework involves four steps: goal & scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment, and interpretation (ISO, 2006), as shown in Fig. 1. Several mature evaluation systems based on LCA were developed worldwide over the past several decades. Eco-indicator 99 (EI99) is a damage-oriented approach and was commissioned as part of the Integrated Product Policy by the Dutch Ministry of Housing, Spatial Planning and the Environment (Goedkoop and Spriensma, 2000). EI99 classifies 11 environmental impact categories into 3 safeguard areas: human health, natural and manmade environments, and natural resources. Moreover, EI99 has proven to be a useful tool for designers to aggregate LCA results into user-friendly units. Environmental priority strategies (EPS), developed by the Centre for Environmental Assessment of Products and Material Systems, is an effective tool for a company's internal product development process (Steen, 1999). This system was created in a top-down manner, and it allocates 18 impact categories into 5 safeguard areas: human health, production capacity of ecosystems, abiotic stock resource indicators, bio-diversity impact indicators, and cultural and recreation value indicators. Impact 2002 links life cycle inventories (elementary flows and other interventions) via 14 midpoint categories to 4 damage categories: human health, ecosystem quality, climate change and resources (Jolliet et al., 2003). These models follow the LCA framework and have been tested through wide application to different products. In addition, there are many other LCA methods, such as CalTOX (USA), Envest (England), and CML2002 (the Netherlands).

For buildings specifically, there are several relevant international projects, such as the European Thematic Network on Practical Recommendations for Sustainable Construction (PRESCO) (Peuportier

* Corresponding author at: Tsinghua University, Haidian District, Beijing, China.
E-mail addresses: eastdawn@tsinghua.edu.cn (X. Li), sushuqh@163.com (S. Su), zhzhg@tsinghua.edu.cn (Z. Zhang), kxlwq@126.com (X. Kong).

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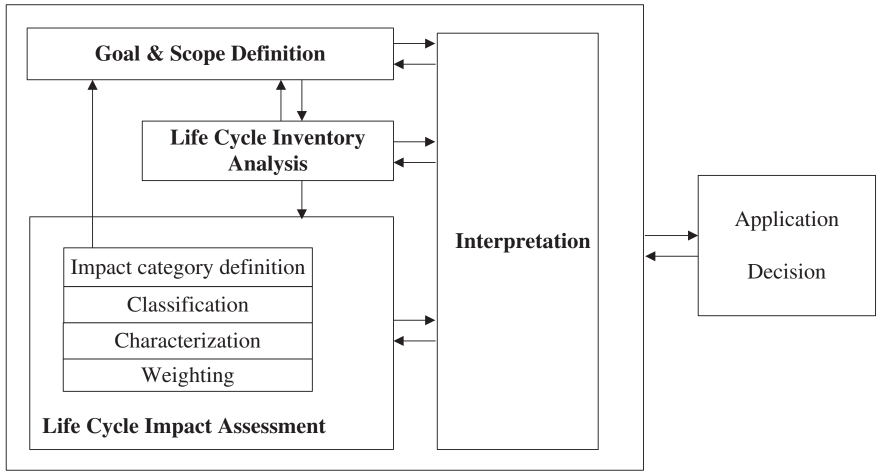

Fig. 1. LCA framework.

et al., 2005), Energy Related Environmental Impact of Buildings (IEA Annex 31, 2005), and Building Environmental Quality for Sustainability through Time (BEQUEST, 2000). The numbers of building EIA tools are increasing all over the world, and many studies compare the tools themselves or the results from different tools (Forsberg and Von Malmborg, 2004; Haapio and Viitaniemi, 2008; Kawazu et al., 2005; Todd et al., 2001). Building for Environmental and Economic Sustainability (BEES) is supported by the U.S. Environmental Protection Agency Environmentally Preferable Purchasing Program; it measures the building environmental performance during raw material acquisition, manufacturing, transportation, installation, use, and waste management by synthesizing the environmental and economic results into a single score (Lippiatt, 2007). "Optimization of global demands in terms of costs, energy and environment within an integrated planning process" (OGIP) is designed for the integrated planning of buildings (Kellenberger and Althaus, 2009; Peuportier et al., 2005); it calculates the environmental impact in the construction and operation phases and helps designers to portray the complex relationships between costs, energy and environmental impact. EcoQuantum was developed by IVAM in the Netherlands and classifies the environmental performance of a building into 11 impact categories (EcoQuantum; Peuportier et al., 2005). These building assessment tools are mature but cannot be directly applied to Chinese buildings because the parameter values of environmental impact potentials applied in the characterization, normalization and weighting steps in the EIA are highly depended on the actual environmental loads of the pollutants discharge area (Yang, 2002). Besides, constructions in different countries vary due to climatic and geographic conditions, raw material qualities, economic data, material manufacturing technologies, fuel structures, energy tariffs, labor and many other factors (Dixit et al., 2010). Thus, it is necessary and valuable to develop a building EIA system adopting parameters according to Chinese resources and environment conditions.

To promote building sustainability in China, several studies have been done by the Chinese government and researchers in the past decades. The General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) and the Standardization Administration of the People's Republic of China (SAC) issued two national LCA standards (GB/T 24040-2008 and GB/T 24044-2008) to guide the LCA of Chinese products (AQSIQ and SAC, 2008a, 2008b). These two voluntary standards are sourced from ISO 14040 and ISO 14044 and support the development of building impact evaluation methods. The Building Environmental Load Evaluation System (BELES) conducts building EIAs based on the endpoint damage oriented approach (Gu, Lin, Gu and Zhu, 2008a); it classifies impacts into 8 midpoint categories and then allocates them into 4 endpoints: resource exhaustion, energy exhaustion, human health damage and ecosystem damage. The inventory data are gathered from many different studies or estimated based on data from other countries, which decreases the accuracy of the results. Furthermore, BELES uses the panel method to calculate weightings, so the results are inevitably subjective. The Life Cycle Green Cost Assessment (LCGCA) combines LCA with life cycle costing to convert the building's environmental loads to environmental costs based on the trading price of carbon dioxide (CO_2) certified emission reductions (Gu, Lin, Zhu, et al., 2008b). However, this model relies heavily on environmental policies and environmental tax mechanisms, which are far from sound in China. In addition, LCGCA is only suitable for projects in which costs are paid by the same party throughout the whole life cycle. The Building Environmental Performance Analysis System (BEPAS) is a premium system funded by the Ministry of Housing and Urban-Rural Development (MOHURD) (Zhang et al., 2006) that has served as a methodological base for the construction industry standard in China - the Standard for Sustainability Assessment of Building Project (MOHURD, 2011). BEPAS allocates building environmental impacts into ecological damage and resource depletion, and then into many sub-categories. The Building Health Impact Assessment System (BHIAS) (Kong, 2010) was developed based on EPS to quantify damages to human health in the life cycle of buildings. It follows the LCA framework and uses willingness to pay (WTP) as the weighting method. BEPAS and BHIAS are relatively mature models in China, and their reliability and operability have been tested through many project applications.

To better apply BEPAS and BHIAS on a larger scale and to improve green construction in China, two limitations should be addressed. First, these two models allocate impacts into different categories, causing problems for comprehensively assessing building environmental and health performance (EHP). Buildings have negative impacts on ecosystems, natural resources and human health, and people are concerned about these effects. An integrated assessment model that covers all these categories will help to scientifically identify major EHP factors and propose effective improvements. Second, in previous studies, these two models serve as post-construction assessment tools to accept the completed work instead of as pre-evaluation tools (Li et al., 2010). The consumption data in previous studies are derived from actual measurements and can only be retrieved after the project is completed. This data collection method limits the practical value of the assessment results. To address the above gaps, the authors proposed a conceptual framework (Li, Su and Zhang, 2014a); however, more details and information, such as the complete assessment approach and flow, data conversion mode, and available weighting methods, should be examined.

Following the LCA framework, this study integrates BEPAS and BHIAS into a new model to quantify combined EHP for buildings. The new assessment model uses engineering quota to acquire the consumption data, and the impacts considered cover three common safeguard